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Hovden

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(54) **DYNAMICALLY RECONFIGURABLE CAPACITIVE SENSOR ARRAY**

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H03K 17/96	(2006.01)
G06F 3/044	(2006.01)
G06F 3/023	(2006.01)
H03K 17/955	(2006.01)
H03K 17/98	(2006.01)

(52) **U.S. Cl.**

CPC ***H03K 17/9622*** (2013.01); ***G06F 3/023*** (2013.01); ***G06F 3/044*** (2013.01); ***H03K 17/955*** (2013.01); *G06F 2203/04101* (2013.01); *H03K 17/98* (2013.01); *H03K 2217/96027* (2013.01)

(58) **Field of Classification Search**

CPC H03K 17/94
USPC 341/20, 21, 33
See application file for complete search history.

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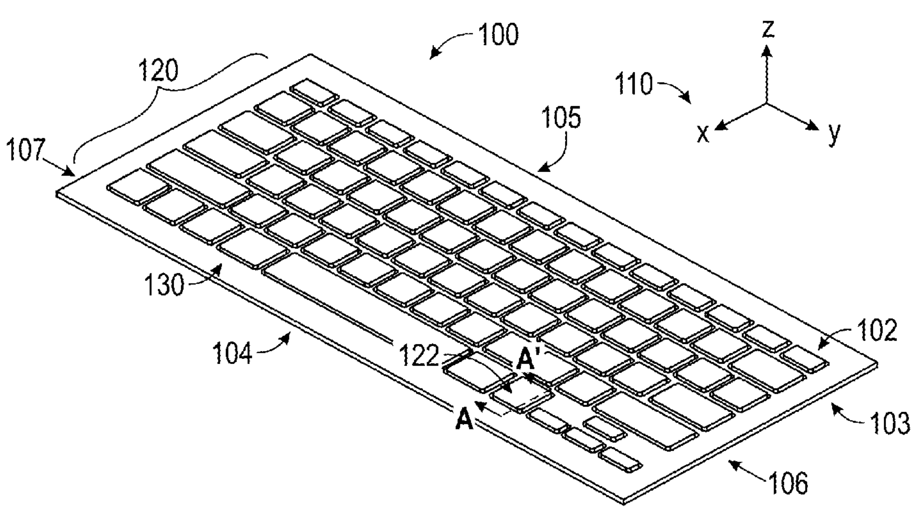
(57) **ABSTRACT**

In a keyboard of the type including a key cap and a capacitive sensor disposed underneath the key cap, a method including operating the capacitive sensor in a first mode configured for near field detection and generating a first variable capacitance, and operating the capacitive sensor in a second mode configured for far field detection and generating a second variable capacitance. The method further includes determining key motion based on the first variable capacitance and determining finger presence based on the second variable capacitance.

15 Claims, 6 Drawing Sheets



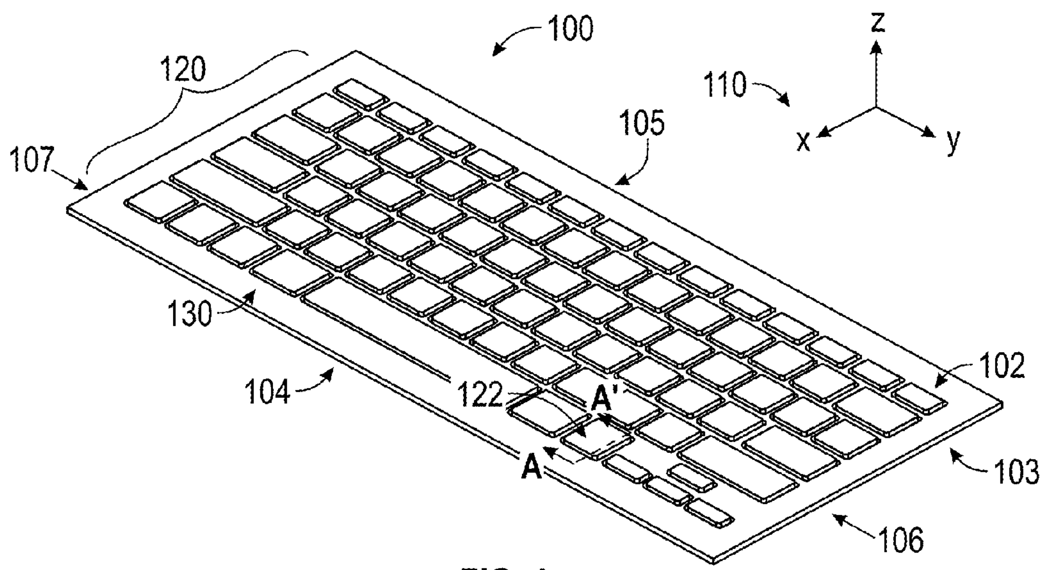

100
120
110
z
x
y
105
107
130
104
122
A'
A
102
103
106

FIG. 1

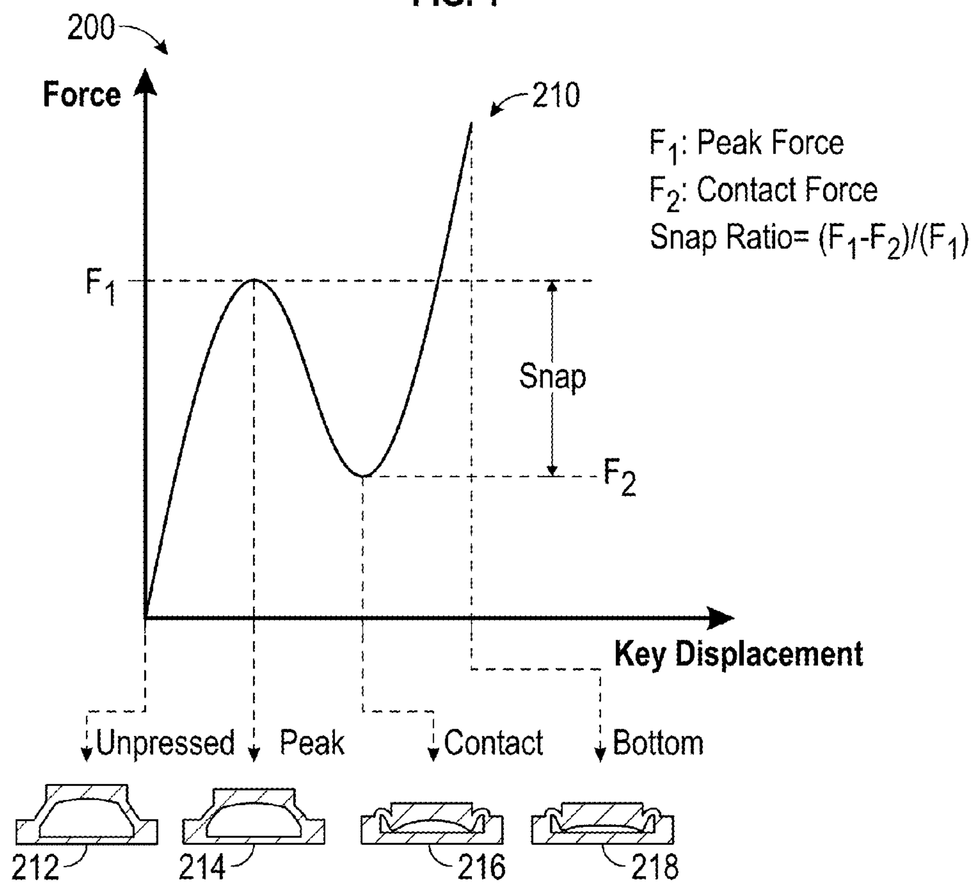

200
Force
210
F1: Peak Force
F2: Contact Force
Snap Ratio= (F1-F2)/(F1)
F1
Snap
F2
Key Displacement
Unpressed
Peak
Contact
Bottom
212
214
216
218

FIG. 2

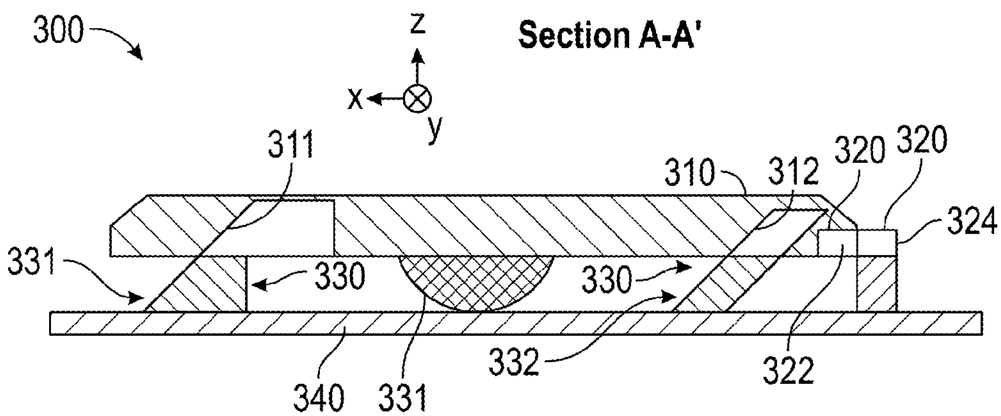

300
Section A-A'
z
x
y
311
310
312
320
320
324
331
330
330
332
322
340
331

FIG. 3A

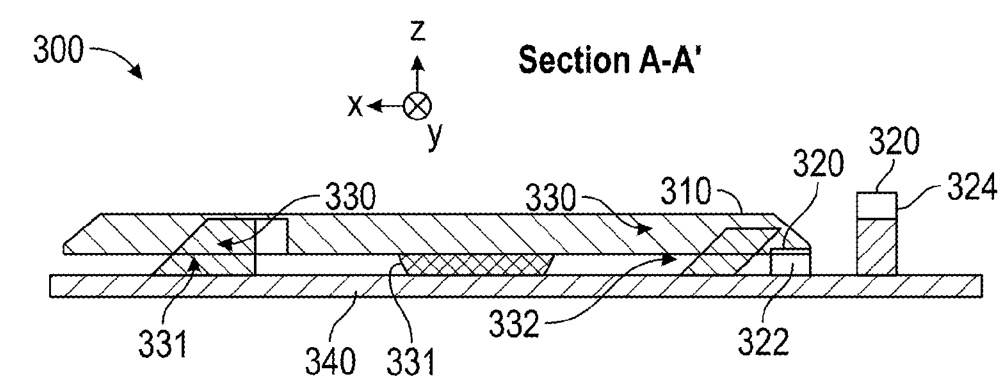

300
Section A-A'
z
x
y
330
330
310
320
320
324
331
340
331
332
322

FIG. 3B

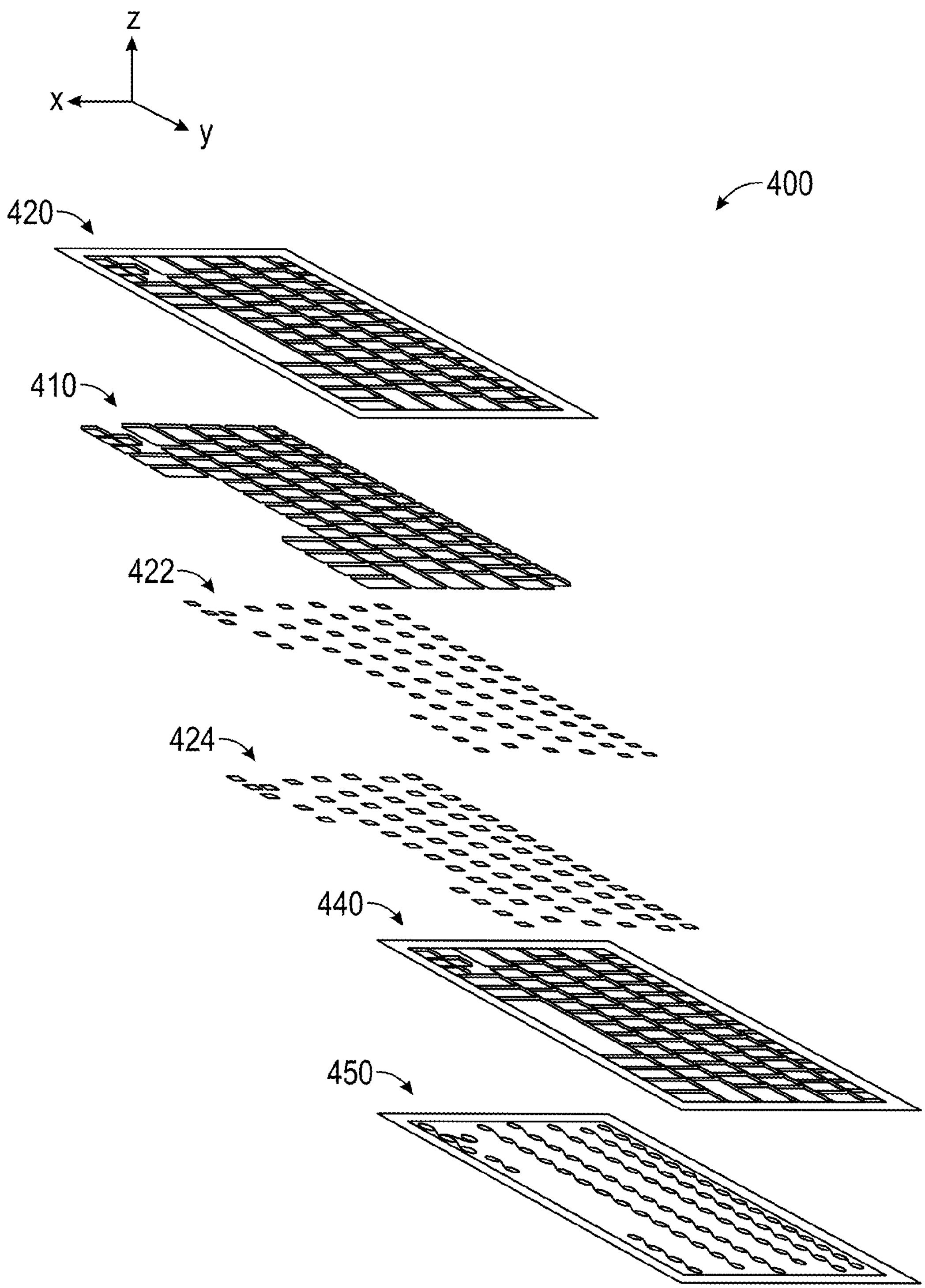
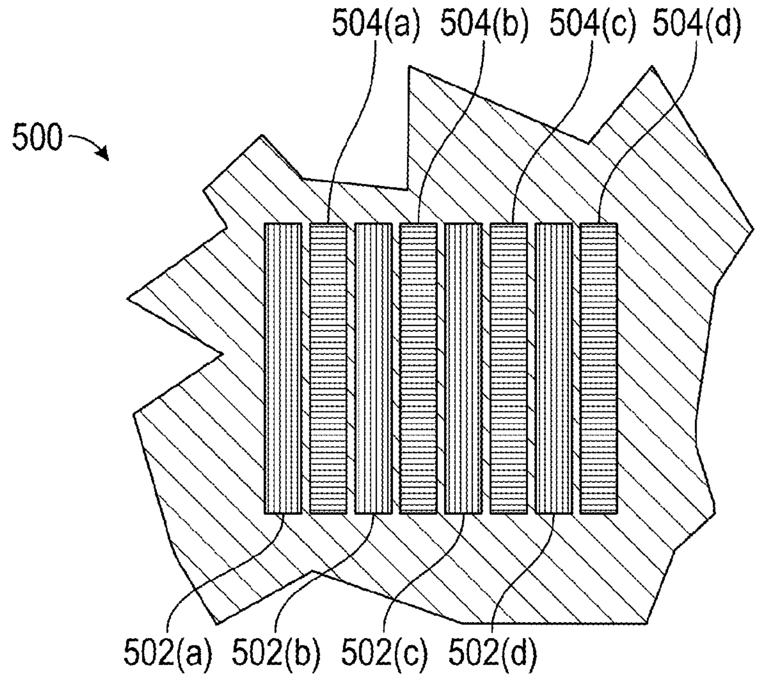
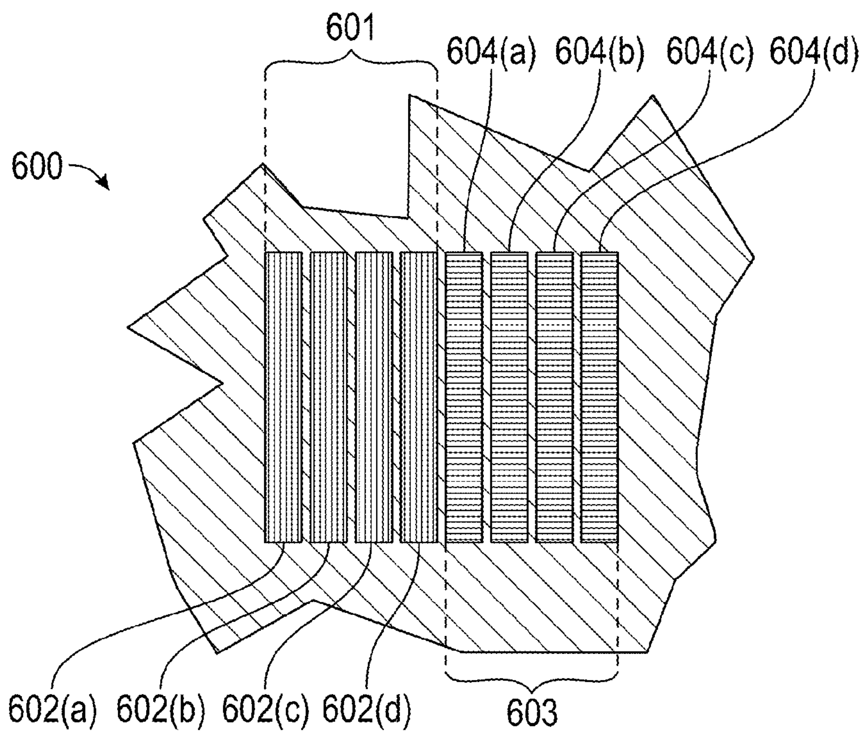


FIG. 4



504(a)
504(b)
504(c)
504(d)
500
502(a)
502(b)
502(c)
502(d)

FIG. 5



601
604(a)
604(b)
604(c)
604(d)
600
602(a)
602(b)
602(c)
602(d)
603

FIG. 6

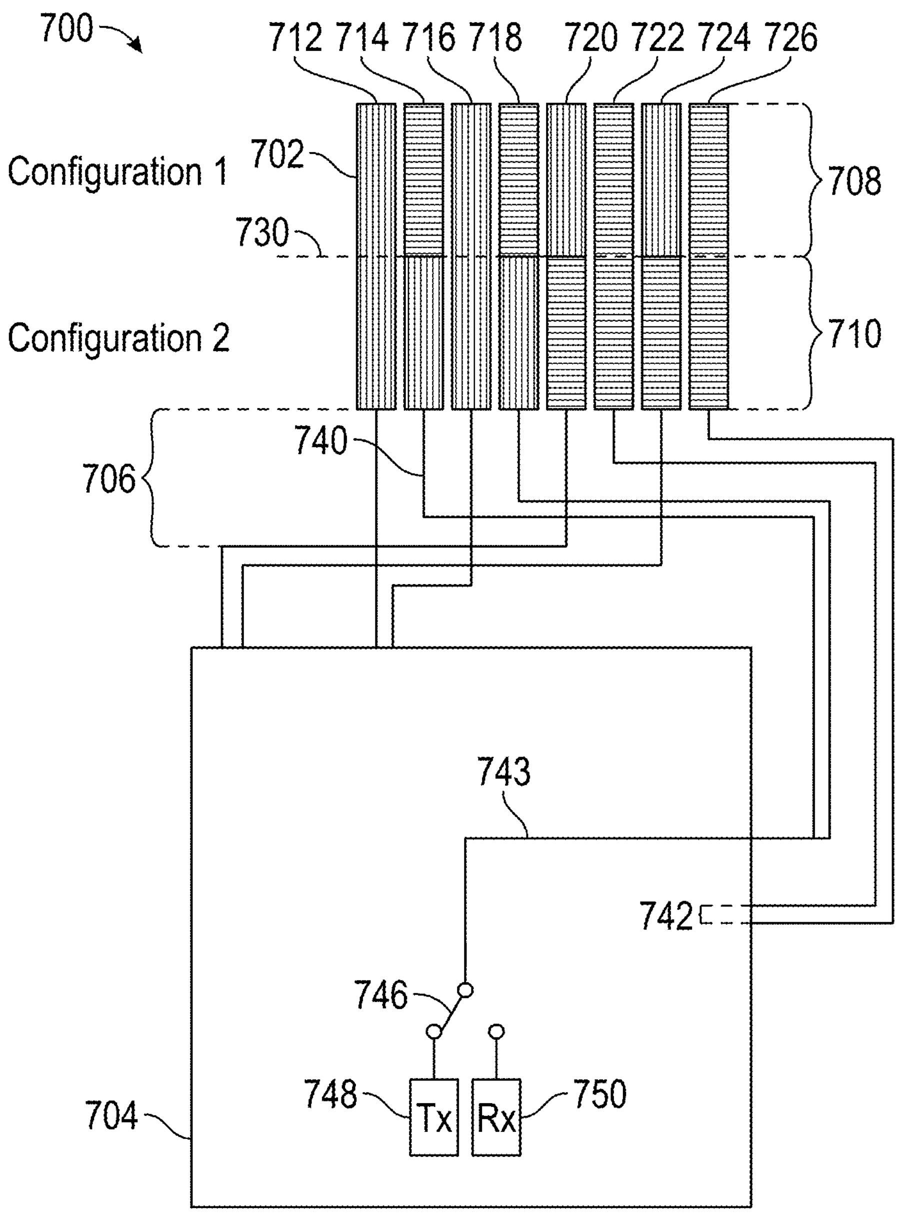

700
712 714 716 718 720 722 724 726
Configuration 1
702
730
708
Configuration 2
710
740
706
743
742
746
748
Tx
Rx
750
704

FIG. 7

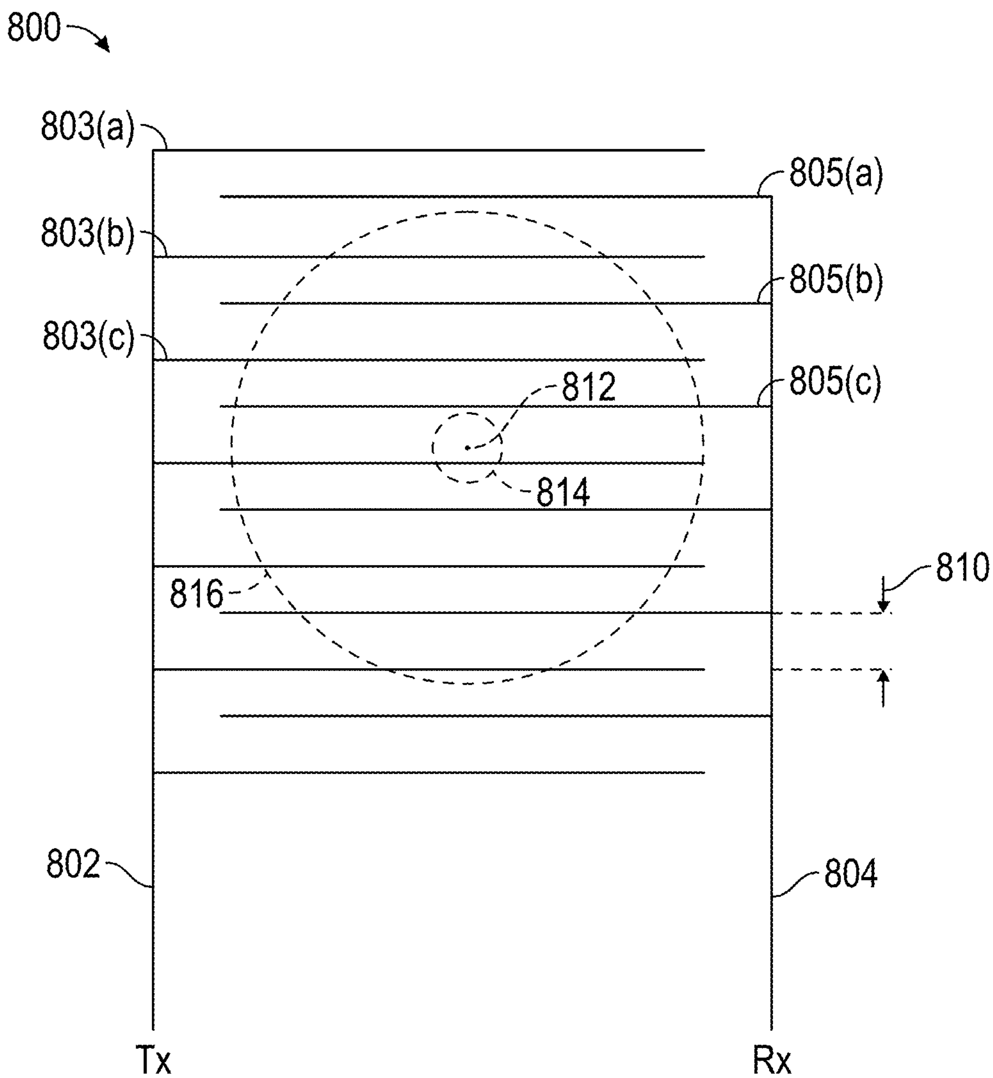


FIG. 8

DYNAMICALLY RECONFIGURABLE CAPACITIVE SENSOR ARRAY

FIELD OF THE INVENTION

This invention generally relates to electronic devices.

BACKGROUND OF THE INVENTION

Pressable touchsurfaces (touch surfaces which can be pressed) are widely used in a variety of input devices, including as the surfaces of keys or buttons for keypads or keyboards, and as the surfaces of touch pads or touch screens. It is desirable to improve the usability of these input systems.

FIG. **2** shows a graph **200** of an example tactile response curve associated with the "snapover" haptic response found in many keys enabled with metal snap domes or rubber domes. Specifically, graph **200** relates force applied to the user by a touchsurface of the key and the amount of key displacement (movement relative to its unpressed position). The force applied to the user may be a total force or the portion of the total force along a particular direction such as the positive or negative press direction. Similarly, the amount of key displacement may be a total amount of key travel or the portion along a particular direction such as the positive or negative press direction.

The force curve **210** shows four key press states **212**, **214**, **216**, **218** symbolized with depictions of four rubber domes at varying amounts of key displacement. The key is in the "unpressed" state **212** when no press force is applied to the key and the key is in the unpressed position (i.e., "ready" position). In response to press input, the key initially responds with some key displacement and increasing reaction force applied to the user. The reaction force increases with the amount of key displacement until it reaches a local maximum "peak force" F_1 in the "peak" state **214**. In the peak state **214**, the metal snap dome is about to snap or the rubber dome is about to collapse. The key is in the "contact" state **216** when the keycap, snap dome or rubber dome, or other key component moved with the keycap makes initial physical contact with the base of the key (or a component attached to the base) with the local minimum "contact force" F_2. The key is in the "bottom" state **218** when the key has travelled past the "contact" state and is mechanically bottoming out, such as by compressing the rubber dome in keys enabled by rubber domes.

A snapover response is defined by the shape of the reaction force curve—affected by variables such as the rate of change, where it peaks and troughs, and the associated magnitudes. The difference between the peak force F_1 and the contact force F_2 can be termed the "snap." The "snap ratio" can be determined as $(F_1-F_2)/F_1$ (or as $100*(F_1-F_2)/F_1$, if a percent-type measure is desired).

Capacitive sensors for detecting a key press are well known. Touch sensors for detecting finger presence are also well known. However, presently known key press sensors and finger presence sensors typically require separate, dedicated electrodes and associated circuitry for implementing the keystroke and proximity functions, respectively. Devices, systems, and methods are thus needed which overcome this shortcoming.

BRIEF SUMMARY OF THE INVENTION

Methods and apparatus are provided for dynamically configuring a capacitive sensor array to selectively operate in one of two sensitivity modes: i) a far field mode for detecting finger presence; and ii) a near field mode for detecting a keystroke which is relatively insensitive to finger presence. Various embodiments provide a processing system coupled to the sensor array for selectively switching blocks of electrodes between functioning as a group of transmitters in one sensitivity mode, and functioning as a group of receivers in the other sensitivity mode. By multiplexing the electrodes in this manner, the same sensing hardware and circuitry can be used to sense both keystroke and finger presence.

BRIEF DESCRIPTION OF DRAWINGS

Example embodiments of the present invention will hereinafter be described in conjunction with the appended drawings which are not to scale unless otherwise noted, where like designations denote like elements, and:

FIG. **1** shows an example keyboard that incorporates one or more implementations of key-based touchsurfaces configured in accordance with the techniques described herein;

FIG. **2** is a graph of an example tactile response that is characteristic of many keys enabled with metal snap domes or rubber domes;

FIGS. **3**A-**3**B are simplified side views of a first example touchsurface assembly configured in accordance with the techniques described herein;

FIG. **4** shows an exploded view of an example keyboard in accordance with the techniques described herein;

FIG. **5** is a schematic layout diagram of a capacitive sensor array configured for near field sensing in accordance with the techniques described herein;

FIG. **6** is a schematic layout diagram of the capacitive sensor array of FIG. **5**, shown dynamically reconfigured for far field sensing in accordance with the techniques described herein;

FIG. **7** is a schematic layout diagram of the capacitive sensor array of FIGS. **5** and **6** coupled to a processing system in accordance with the techniques described herein; and

FIG. **8** is a schematic diagram of an exemplary capacitive sensor configured for near field sensing, shown superimposed with a graphical representation of an increasing area of contact with a dielectric material in accordance with the techniques described herein.

DETAILED DESCRIPTION OF THE INVENTION

The following detailed description is merely exemplary in nature and is not intended to limit the invention or the application and uses of the invention.

Various embodiments of the present invention provide input devices and methods that facilitate improved usability, thinner devices, easier assembly, lower cost, more flexible industrial design, or a combination thereof. These input devices and methods involve pressable touchsurfaces that may be incorporated in any number of devices. As some examples, pressable touchsurfaces may be implemented as surfaces of touchpads, touchscreens, keys, buttons, and the surfaces of any other appropriate input device. Thus, some non-limiting examples of devices that may incorporate pressable touchsurfaces include personal computers of all sizes and shapes, such as desktop computers, laptop computers, netbooks, ultrabooks, tablets, e-book readers, personal digital assistants (PDAs), and cellular phones including smart phones. Additional example devices include data input devices (including remote controls, integrated keyboards or keypads such as those within portable computers, or peripheral keyboards or keypads such as those found in tablet covers or stand-alone keyboards, control panels, and computer mice), and data output devices (including display screens and printers). Other examples include remote terminals, kiosks, point-of-sale devices, video game machines (e.g., video game consoles, portable gaming devices, and the like) and media devices (including recorders, editors, and players such as televisions, set-top boxes, music players, digital photo frames, and digital cameras).

The discussion herein focuses largely on rectangular touchsurfaces. However, the touchsurfaces for many embodiments can comprise other shapes. Example shapes include triangles, quadrilaterals, pentagons, polygons with other numbers of sides, shapes similar to polygons with rounded corners or nonlinear sides, shapes with curves, elongated or circular ellipses circles, combinations shapes with portions of any of the above shapes, non-planar shapes with concave or convex features, and any other appropriate shape.

In addition, although the discussion herein focuses largely on the touchsurfaces as being atop rigid bodies that undergo rigid body motion, some embodiments may comprise touchsurfaces atop pliant bodies that deform. "Rigid body motion" is used herein to indicate motion dominated by translation or rotation of the entire body, where the deformation of the body is negligible. Thus, the change in distance between any two given points of the touchsurface is much smaller than an associated amount of translation or rotation of the body.

Also, in various implementations, pressable touchsurfaces may comprise opaque portions that block light passage, translucent or transparent portions that allow light passage, or both.

FIG. **1** shows an example keyboard **100** that incorporates a plurality of (two or more) pressable key-based touchsurfaces configured in accordance with the techniques described herein. The example keyboard **100** comprises rows of keys **120** of varying sizes surrounded by a keyboard bezel **130**. Keyboard **100** has a QWERTY layout, even though the keys **120** are not thus labeled in FIG. **1**. Other keyboard embodiments may comprise different physical key shapes, key sizes, key locations or orientations, or different key layouts such as DVORAK layouts or layouts designed for use with special applications or non-English languages. In some embodiments, the keys **120** comprise keycaps that are rigid bodies, such as rigid rectangular bodies having greater width and breadth than depth (depth being in the Z direction as explained below). Also, other keyboard embodiments may comprise a single pressable key-based touchsurface configured in accordance with the techniques described herein, such that the other keys of these other keyboard embodiments are configured with other techniques.

Orientation terminology is introduced here in connection with FIG. **1**, but is generally applicable to the other discussions herein and the other figures unless noted otherwise. This terminology introduction also includes directions associated with an arbitrary Cartesian coordinate system. The arrows **110** indicate the positive directions of the Cartesian coordinate system, but do not indicate an origin for the coordinate system. Definition of the origin will not be needed to appreciate the technology discussed herein.

The face of keyboard **100** including the exposed touchsurfaces configured to be pressed by users is referred to as the "top" **102** of the keyboard **100** herein. Using the Cartesian coordinate directions indicated by the arrows **110**, the top **102** of the keyboard **100** is in the positive-Z direction relative to the bottom **103** of the keyboard **100**. The part of the keyboard **100** that is typically closer to the body of a user when the keyboard **100** is in use atop a table top is referred to as the "front" **104** of the keyboard **100**. In a QWERTY layout, the front **104** of the keyboard **100** is closer to the space bar and further from the alphanumeric keys. Using the Cartesian coordinate directions indicated by the arrows **110**, the front **104** of the keyboard **100** is in the positive-X direction relative to the back **105** of the keyboard **100**. In a typical use orientation where the top **102** of the keyboard **100** is facing upwards and the front **104** of the keyboard **100** is facing towards the user, the "right side" **106** of the keyboard **100** is to the right of a user. Using the Cartesian coordinate directions indicated by the arrows **110**, the right side **106** of the keyboard **100** is in the positive-Y direction relative to the "left side" **107** of the keyboard **100**. With the top **102**, front **104**, and right side **106** thus defined, the "bottom" **103**, "back" **105**, and "left side" **107** of the keyboard **100** are also defined.

Using this terminology, the press direction for the keyboard **100** is in the negative-Z direction, or vertically downwards toward the bottom of the keyboard **100**. The X and Y directions are orthogonal to each other and to the press direction. Combinations of the X and Y directions can define an infinite number of additional lateral directions orthogonal to the press direction. Thus, example lateral directions include the X direction (positive and negative), the Y direction (positive and negative), and combination lateral directions with components in both the X and Y directions but not the Z direction. Motion components in any of these lateral directions is sometimes referred herein as "planar," since such lateral motion components can be considered to be in a plane orthogonal to the press direction.

Some or all of the keys of the keyboard **100** are configured to move between respective unpressed and pressed positions that are spaced in the press direction and in a lateral direction orthogonal to the press direction. That is, the touchsurfaces of these keys exhibit motion having components in the negative Z-direction and in a lateral direction. In the examples described herein, the lateral component is usually in the positive X-direction or in the negative X-direction for ease of understanding. However, in various embodiments, and with reorientation of select key elements as appropriate, the lateral separation between the unpressed and the pressed positions may be solely in the positive or negative X-direction, solely in the positive or negative Y-direction, or in a combination with components in both the X and Y directions.

Thus, these keys of the keyboard **100** can be described as exhibiting "diagonal" motion from the unpressed to the pressed position. This diagonal motion is a motion including both a "Z" (or vertical) translation component and a lateral (or planar) translation component. Since this planar translation occurs with the vertical travel of the touchsurface, it may be called "planar translational responsiveness to vertical travel" of the touchsurface, or "vertical-lateral travel."

Some embodiments of the keyboard **100** comprise keyboards with leveled keys that remain, when pressed during normal use, substantially level in orientation through their respective vertical-lateral travels. That is, the keycaps of these leveled keys (and thus the touchsurfaces of these keys) exhibit little or no rotation along any axes in response to presses that occur during normal use. Thus, there is little or no roll, pitch, and yaw of the keycap and the associated touchsurfaces remain relatively level and substantially in the same orientation during their motion from the unpressed position to the pressed position.

In various embodiments, the lateral motion associated with the vertical-lateral travel can improve the tactile feel of the key by increasing the total key travel for a given amount of vertical travel in the press direction. In various embodiments, the vertical-lateral travel also enhances tactile feel by imparting to users the perception that the touchsurface has travelled a larger vertical distance than actually travelled. For example, the lateral component of vertical-lateral travel may apply tangential friction forces to the skin of a finger pad in contact with the touchsurface, and cause deformation of the skin and finger pad that the user perceives as additional vertical travel. This then creates a tactile illusion of greater vertical travel. In some embodiments, returning the key from the pressed to the unpressed position on the return stroke also involves simulating greater vertical travel using lateral motion.

To enable the keys **120** of the keyboard **100** with vertical-lateral travel, the keys **120** are parts of key assemblies each comprising mechanisms for effecting planar translation, readying the key **120** by holding the associated keycap in the unpressed position, and returning the key **120** to the unpressed position. Some embodiments further comprise mechanisms for leveling keycaps. Some embodiments achieve these functions with a separate mechanism for each function, while some embodiments achieve two or more of these functions using a same mechanism. For example, a "biasing" mechanism may provide the readying function, the returning function, or both the readying and returning functions. Mechanisms which provide both readying and returning functions are referred to herein as "ready/return" mechanisms. As another example, a leveling/planar-translation-effecting mechanisms may level and effect planar translation. As further examples, other combinations of functions may be provided by a same mechanism.

The keyboard **100** may use any appropriate technology for detecting presses of the keys of the keyboard **100**. For example, the keyboard **100** may employ a key switch matrix based on conventional resistive membrane switch technology. The key switch matrix may be located under the keys **120** and configured to generate a signal to indicate a key press when a key **120** is pressed. Alternatively, the example keyboard **100** may employ other key press detection technology to detect any changes associated with the fine or gross change in position or motion of a key **120**. Example key press detection technologies include various capacitive, resistive, inductive, magnetic, force or pressure, linear or angular strain or displacement, temperature, aural, ultrasonic, optical, and other suitable techniques. With many of these technologies, one or more preset or variable thresholds may be defined for identifying presses and releases.

As a specific example, capacitive sensor electrodes may be disposed under the touchsurfaces, and detect changes in capacitance resulting from changes in press states of touchsurfaces. The capacitive sensor electrodes may utilize "self capacitance" (or "absolute capacitance") sensing methods based on changes in the capacitive coupling between the sensor electrodes and the touchsurface. In some embodiments, the touchsurface is conductive in part or in whole, or a conductive element is attached to the touchsurface, and held at a constant voltage such as system ground. A change in location of the touchsurface alters the electric field near the sensor electrodes below the touchsurface, thus changing the measured capacitive coupling. In one implementation, an absolute capacitance sensing method operates with a capacitive sensor electrode underlying a component having the touchsurface, modulates that sensor electrodes with respect to a reference voltage (e.g., system ground), and detects the capacitive coupling between that sensor electrode and the component having the touchsurface for gauging the press state of the touchsurface.

Some capacitive implementations utilize "mutual capacitance" (or "transcapacitance") sensing methods based on changes in the capacitive coupling between sensor electrodes. In various embodiments, the proximity of a touchsurface near the sensor electrodes alters the electric field between the sensor electrodes, thus changing the measured capacitive coupling. The touchsurface may be a conductive or non-conductive, electrically driven or floating, as long as its motion causes measurable change in the capacitive coupling between sensor electrodes. In some implementations, a transcapacitive sensing method operates by detecting the capacitive coupling between one or more transmitter sensor electrodes (also "transmitters") and one or more receiver sensor electrodes (also "receivers"). Transmitter sensor electrodes may be modulated relative to a reference voltage (e.g., system ground) to transmit transmitter signals. Receiver sensor electrodes may be held substantially constant relative to the reference voltage to facilitate receipt of resulting signals. A resulting signal may comprise effect(s) corresponding to one or more transmitter signals, and/or to one or more sources of environmental interference (e.g., other electromagnetic signals). Sensor electrodes may be dedicated transmitters or receivers, or may be configured to both transmit and receive.

In one implementation, a trans-capacitance sensing method operates with two capacitive sensor electrodes underlying a touchsurface, one transmitter and one receiver. The resulting signal received by the receiver is affected by the transmitter signal and the location of the touchsurface.

In some embodiments, the sensor system used to detect touchsurface presses may also detect pre-presses. For example, a capacitive sensor system may also be able to detect an input object hovering over but not contacting a touch surface. As another example, a capacitive sensor system may be able to detect an input object lightly touching a touchsurface, such that the user performs a non-press contact on the touchsurface, and does not depress the touchsurface sufficiently to be considered a press.

Some embodiments are configured to gauge the amount of force being applied on the touchsurface from the effect that the force has on the sensor signals. That is, the amount of depression of the touchsurface is correlated with one or more particular sensor readings, such that the amount of press force can be determined from the sensor reading(s). These types of systems can support multi-stage touchsurface input by distinguishing and responding differently to two or more of the following: non-contact hover, non-press contact, and one, two, or more levels of press.

In some embodiments, substrates used for sensing are also used to provide backlighting associated with the touchsurfaces. As a specific example, in some embodiments utilizing capacitive sensors underlying the touchsurface, the capacitive sensor electrodes are disposed on a transparent or translucent circuit substrate such as polyethylene terephthalate (PET), another polymer, or glass. Some of those embodiments use the circuit substrate as part of a light guide system for backlighting symbols viewable through the touchsurfaces.

FIG. **1** also shows a section line A-A' relative to the key **122** of the keyboard **100**, which will be discussed below.

The keyboard **100** may be communicably coupled with a processing system **190** through communications channel **192**. Connection **192** may be wired or wireless. The processing system **190** may comprise one or more ICs (integrated circuits) having appropriate processor-executable instructions for operating the keyboard **100**, such as instructions for operating key press sensors, processing sensor signals, responding to key presses, and the like. In some embodiments, the keyboard **100** is integrated in a laptop computer or a tablet computer cover, and the processing system **190** comprises an IC containing instructions to operate keyboard sensors to determine the extent keys has been touched or pressed, and to provide an indication of touch or press status to a main CPU of the laptop or tablet computer, or to a user of the laptop or tablet computer.

While the orientation terminology, vertical-lateral travel, sensing technology, and implementation options discussed here focuses on the keyboard **100**, these discussions are readily analogized to other touchsurfaces and devices described herein.

Various embodiments in accordance with the techniques described herein, including embodiments without metal snap domes or rubber domes, provide force response curves similar to the curve **210** of FIG. **2**. Many tactile keyboard keys utilize snap ratios no less than 0.4 and no more than 0.6. Other tactile keyboard keys may use snap ratios outside of these ranges, such as no less than 0.3 and no more than 0.5, and no less than 0.5 and no more than 0.7.

Other embodiments provide other response curves having other shapes, including those with force and key travel relationships that are linear or nonlinear or which have constantly varying slopes. The force response curves may also be non-monotonic, monotonic, or strictly monotonic.

For example, the keys **120** made in accordance with the techniques described herein may be configured to provide the response shown by curve **210**, or any appropriate response curve. The reaction force applied to a user may increase linearly or nonlinearly relative to an amount of total key travel, an amount of key travel the press direction, or an amount of key travel in a lateral direction. As a specific example, the force applied may increase with a constant slope relative to the amount of key travel for up to a first amount of force or key movement relative to its unpressed position, and then plateau (with constant force) or decrease for up to a second amount of force or key movement.

FIGS. **3**A-**3**B are simplified cross-sectional views of a first example touchsurface assembly. The key assembly **300** may be used to implement various keys, including the key **122** of the keyboard **100**. In the embodiment where FIGS. **3**A-**3**B depict the key **122**, these figures illustrate A-A' sectional views of the key **122**. FIG. **3**A shows the example key assembly **300** including a resiliently deformable (e.g., rubber) dome **331** in an unpressed position, and FIG. **3**B shows the same key assembly and rubber dome in a pressed position. The key assembly **300** may also be used in other devices utilizing keys, including keyboards other than the keyboard **100** and any other appropriate key-using device. Further, assemblies analogous to the key assembly **300** may be used to enable non-key touchsurface assemblies such as buttons, opaque touchpads, touchscreens, or any of the touchsurface assemblies described herein.

The key assembly **300** includes a keycap **310** that is visible to users and configured to be pressed by users, a ready/return mechanism **320**, and a base **340**. The unpressed and pressed positions of the keycap **310** are spaced in a press direction and in a first lateral direction orthogonal to the press direction. The press direction is analogous to the key motion found in conventional keyboards lacking lateral key motion, is in the negative-Z direction, and is the primary direction of press and key motion. In many keyboards the press direction is orthogonal to the touchsurface of the keycap or the base of the key, such that users would consider the press direction to be downwards toward the base.

The components of the key assembly **300** may be made from any appropriate material, including plastics such as polycarbonate (PC), acrylonitrile butadiene styrene (ABS), nylon, and acetal, metals such as steel and aluminum, elastomers such as rubber, and various other materials. In various embodiments, the keycap **310** is configured to be substantially rigid, such that the touchsurface of the keycap **310** appears to unaided human senses to move with rigid body motion between its unpressed and pressed positions during normal operation.

The ready/return mechanism **320** is a type of "biasing mechanism" that provides both readying and returning functions. The ready/return mechanism **320** physically biases the keycap **310** during at least part of the key press operation. It should be noted that a mechanism which only provides readying or returning function may also be termed a "biasing mechanism," if it biases the keycap **310** during at least part of the key press operation. The ready/return mechanism **320** is configured to hold the keycap **310** in its unpressed position so that the keycap **310** is ready to be pressed by a user. In addition, the ready/return mechanism **320** is also configured to return the keycap **310** partially or entirely to the unpressed position in response to a release of the press force to keycap **310**. The release of the press force may be a removal of the press force, or a sufficient reduction of press force such that the key assembly is able to return the keycap **310** to the unpressed position as a matter of normal operation. In the example embodiment of FIG. **3**, the key assembly **300** utilizes magnetically coupled components **322**, **324** to form the ready/return mechanism **320**. Magnetically coupled components **322**, **324** may both comprise magnets, or one may comprise a magnet while the other comprise a magnetically coupled material such as a ferrous material, a paramagnetic material, or a diamagnetic material. Although magnetically coupled components **322**, **324** are each shown as a single rectangular shape, either or both magnetically coupled components **322**, **324** may comprise non-rectangular cross-section(s) or comprise a plurality of magnetically coupled subcomponents having the same or different cross sections. For example, magnetically coupled component **322** or **324** may comprise a magnetic, box-shaped subcomponent disposed against a central portion of a ferrous, U-shaped subcomponent.

In some implementations, the magnetically coupled component **324** is physically attached to a bezel or base proximate to the keycap **310**. The magnetically coupled component **322** is physically attached to the keycap and magnetically interacts with the magnetically coupled component **324**. The physical attachment of the magnetically coupled components **322**, **324** may be direct or indirect (indirectly being through one or more intermediate components), and may be accomplished by press fits, adhesives, or any other technique or combination of techniques. The amount of press force needed on the keycap to overcome the magnetic coupling (e.g., overpower the magnetic attraction or repulsion) can be customized based upon the size, type, shape, and positions of the magnetically coupling components **322**, **324** involved.

The key assembly **300** comprises a planar-translation-effecting (PTE) mechanism **330** configured to impart planar translation to the keycap **310** when it moves between the unpressed and pressed positions, such that a nonzero component of lateral motion occurs. The PTE mechanism **330** is formed from parts of the keycap **310** and the base **340**, and comprises four ramps (two ramps **331**, **332** are visible in

FIGS. **3**A-B) disposed on the base **340**. These four ramps are located such that they are proximate to the corners of the keycap **310** when the key assembly **300** is assembled. In the embodiment shown in FIGS. **3**A-B, these four ramps (including ramps **331**, **332**) are simple, sloped planar ramps located at an angle to the base **340**. These four ramps (including ramps **331**, **332**) are configured to physically contact corresponding ramp contacting features (two ramp contacting features **311**, **312** are visible in FIGS. **3**A-B) disposed on the underside of the keycap **310**. The ramp contacting features of the keycap **310** may be any appropriate shape, including ramps matched to those of the ramps on the base **340**.

In response to a press force applied to the touchsurface of the keycap **310** downwards along the press direction, the ramps on the base **340** (including ramps **331**, **332**) provide reaction forces. These reaction forces are normal to the ramps and include lateral components that cause the keycap **310** to exhibit lateral motion. The ramps and some retention or alignment features that mate with other features in the bezel or other appropriate component (not shown) help retain and level the keycap **310**. That is, they keep the keycap **310** from separating from the ramps and in substantially the same orientation when travelling from the unpressed to the pressed position.

As shown by FIGS. **3**A-B, the keycap **310** moves in the press direction (negative Z-direction) in response to a sufficiently large press force applied to the top of the keycap **310**. As a result, the keycap **310** moves in a lateral direction (in the positive X-direction) and in the press direction (in the negative Z-direction) due to the reaction forces associated with the ramps. The ramp contacting features (e.g., **311**, **312**) of the keycap **310** ride on the ramps of the base **340** (e.g., **331**, **332**) as the keycap **310** moves from the unpressed to the pressed position. This motion of the keycap **310** moves the magnetically coupled components **322**, **324** relative to each other, and changes their magnetic interactions.

FIG. **3**B shows the keycap **310** in the pressed position. For the key assembly **300**, the keycap **310** has moved to the pressed position when it directly or indirectly contacts the base **340** or has moved far enough to be sensed as a key press. FIG. **3**A-B do not illustrate the sensor(s) used to detect the press state of the keycap **310**, and such sensor(s) may be based on any appropriate technology, as discussed above.

When the press force is released, the ready/return mechanism **320** returns the keycap **310** to its unpressed position. The attractive forces between the magnetically coupled components **322**, **324** pull the keycap **310** back up the ramps (including the ramps **331**, **322**), toward the unpressed position.

Many embodiments using magnetic forces utilize permanent magnets. Example permanent magnets include, in order of strongest magnetic strength to the weakest: neodymium iron boron, samarium cobalt, alnico, and ceramic. Neodymium-based magnets are rare earth magnets, and are very strong magnets made from alloys of rare earth elements. Alternative implementations include other rare earth magnets, non-rare earth permanent magnets, and electromagnets.

Although the key assembly **300** utilizes magnetically coupled components to form its ready/return mechanism **320**, various other techniques can be used instead or in addition to such magnetic techniques in other embodiments. In addition, separate mechanisms may be used to accomplish the readying and returning functions separately. For example, one or more mechanisms may retain the keycap in its ready position and one or more other mechanisms may return the keycap to its ready position. Examples of other readying, returning, or ready/return mechanisms include buckling elastomeric structures, snapping metallic domes, deflecting plastic or metal springs, stretching elastic bands, bending cantilever beams, and the like. In addition, in some embodiments, the ready/return mechanism push (instead of pull) the keycap **310** to resist keycap motion to the pressed position or to return it to the unpressed position. Such embodiments may use magnetic repulsion or any other appropriate technique imparting push forces.

Many variations of or additions to the components of the key assembly **300** are possible. For example, other embodiments may include fewer or more components. As a specific example, another key assembly may incorporate any number of additional aesthetic or functional components. Some embodiments include bezels that provide functions such as hiding some of the key assembly from view, protecting the other components of the key assembly, helping to retain or guide the touchsurface of the key assembly, or some other function.

As another example, other embodiments may comprise different keycaps, readying mechanisms, returning mechanisms, PTE mechanisms, leveling mechanisms, or bases. As a specific example, the keycap **310**, the base **340**, or another component that is not shown may comprise protrusions, depressions, or other features that help guide or retain the keycap **310**. As another specific example, some embodiments use non-ramp techniques in place or (or in addition to) ramps to effect planar translation. Examples other PTE mechanisms include various linkage systems, cams, pegs and slots, bearing surfaces, and other motion alignment features.

As yet another example, although the PTE mechanism **330** is shown in FIGS. **3**A-B as having ramps disposed on the base **340** and ramp contacting features disposed on the keycap **310**, other embodiments may have one or more ramps disposed on the keycap **310** and ramp contacting features disposed on the base **340**. Also, the PTE mechanism **330** is shown in FIGS. **3**A-B as having ramps **331**, **332** with simple, sloped plane ramp profiles. However, in various embodiments, the PTE mechanism **330** may utilize other profiles, including those with linear, piecewise linear, or nonlinear sections, those having simple or complex curves or surfaces, or those including various convex and concave features. Similarly, the ramp contacting features on the keycap **310** may be simple or complex, and may comprise linear, piecewise linear, or nonlinear sections. As some specific examples, the ramp contacting features may comprise simple ramps, parts of spheres, sections of cylinders, and the like. Further, the ramp contacting features on the keycap **310** may make point, line, or surface contact the ramps on the base **340** (including ramps **331**, **332**). "Ramp profile" is used herein to indicate the contour of the surfaces of any ramps used for the PTE mechanisms. In some embodiments, a single keyboard may employ a plurality of different ramp profiles in order to provide different tactile responses for different keys.

As a further example, embodiments which level their touchsurfaces may use various leveling techniques which use none, part, or all of the associate PTE mechanism.

FIG. **4** shows an exploded view of an example keyboard construction **400** in accordance with the techniques described herein. A construction like the keyboard construction **400** may be used to implement any number of different keyboards, including keyboard **100**. Proceeding from the top to the bottom of the keyboard, the bezel **420** comprises a plurality of apertures through which keycaps **410** of various sizes are accessible in the final assembly. Magnetically coupled components **422**, **424** are attached to the keycaps **410** or the base **440**, respectively. The base **440** comprises a plurality of PTE mechanisms (illustrated as simple rectangles on the base **440**) configured to guide the motion of the keycaps **410**. Underneath the base **440** is a key sensor **450**, which comprises one or more layers of circuitry disposed on one or more substrates.

Various details have been simplified for ease of understanding. For example, adhesives that may be used to bond components together are not shown. Also, various embodiments may have more or fewer components than shown in keyboard construction **400**, or the components may be in a different order. For example, the base and the key sensor **450** may be combined into one component, or swapped in the stack-up order.

FIG. **5** is a schematic layout diagram of a capacitive sensor array **500** configured for near field sensing in accordance with the techniques described herein. More particularly, the array **500** includes one or more transmitter electrodes **502**(*a*), **502**(*b*) . . . **502**(*d*) interleaved with one or more receiver electrodes **504**(*a*), **504**(*b*) . . . **504**(*d*). In the near field arrangement shown in FIG. **5**, the thickness and spacing of the electrodes are selected to be insensitive to conductive objects (such as a finger). This allows the sensor to function as a keystroke detector unencumbered by finger proximity. In an embodiment, keystroke detection employs a deformable dielectric disposed between the key cap and the sensor. During a downward keystroke, the deformable dielectric (which has a higher dielectric constant than air) spreads out over the sensor surface, changing the capacitance response of the sensor. This changing capacitance can be used to determine the amount of force applied to the key cap or, alternatively, whether the applied force meets or exceeds a threshold amount of force, to thereby detect a keystroke.

When it is desired to employ the sensor array as a far field sensor to detect finger presence, the sensor may be dynamically reconfigured to reallocate some of the transmitters as receiver, and vice-versa.

More particularly and referring now to FIG. **6**, a schematic layout diagram of a capacitive sensor array **600** includes a block **601** of one or more adjacent transmitter electrodes **602**(*a*), **602**(*b*) . . . **602**(*d*), and a block **603** of one or more adjacent receiver electrodes **604**(*a*), **604**(*b*) . . . **604**(*d*). In the far field arrangement of FIG. **6**, the block **601** of adjacent transmitters effectively functions as a single, relatively wide transmitter electrode, and the block **603** of adjacent receivers effectively functions as a single, relatively wide receiver electrode. This far field arrangement is particularly sensitive to conductive objects (e.g., a finger), and allows the sensor **600** to function as a proximity sensor due to the greater extent (relative to the configuration of FIG. **5**) the field lines bridging the transmitter **601** and the receiver **603** extend into space.

FIG. **7** is a schematic layout diagram **700** of the capacitive sensor array of FIGS. **5** and **6** coupled to a processing system in accordance with the techniques described herein. More particularly, the schematic layout diagram **700** includes a dynamically reconfigurable sensor array **702**, a processing system **704**, and lead lines **706** coupling the individual electrodes of the sensor to respective terminals of the processing system.

The sensor array **702** includes a plurality of electrodes **712-726**, each connected to a corresponding terminal of a processing system (described in greater detail below). The electrodes **712-726** may be alternately configured in a first configuration **708** (shown above a line **730**) for operating the sensor **702** in a near field mode, and a second configuration **710** (shown below the line **730**) for operating the sensor **702** in a far field mode. Specifically, when the sensor **702** is configured to operate in the near field mode (configuration **708**), the following electrodes are configured to operate as transmitters: **712**, **716**, **720**, and **724**; and the following electrodes are configured to operate as receivers: **714**, **718**, **722**, and **726**. Alternatively, when the sensor **702** is configured to operate in the far field mode (configuration **710**), the following electrodes are configured to operate as transmitters: **712**, **714**, **716**, and **718**; and the following electrodes are configured to operate as receivers: **720**, **722**, **724**, and **726**.

In various embodiments, the processing system may dynamically reconfigure the sensor to selectively operate in the near field mode or the far field mode by changing the function of a plurality of electrodes from that of a transmitter to that of a receiver, or vice-versa. An individual electrode may be selectively employed as either a transmitter electrode or a receiver electrode by connecting that electrode to a corresponding transmitter or receiver circuit within (or otherwise associated) with the processing system. In an embodiment, each individual electrode may be selectively connected to a respective transmitter or receiver circuit. Alternatively, blocks of electrodes may be selectively connected to a common transmitter or receiver circuit.

By way of illustration and without limiting the generality of the foregoing, an exemplary electrode **714** may be connected to an individual terminal **744** of the processing system **704** by a conductive routing trace **740**. The terminal **744**, in turn, may be connected to a switch **746** (e.g., a multiplexor circuit) either inside or external to the processing system. When it is desired to operate the electrode **714** as a transmitter, the switch **746** connects the electrode, via the terminal **744**, to a transmitter circuit **748**. When it is desired to operate the electrode **714** as a receiver, the switch **746** connects the electrode, via the terminal **744**, to a receiver circuit **7750**.

In an embodiment, the various terminals associated with a particular microcontroller bay be grouped into blocks, such as blocks **742** and **743**, such that an entire block of terminals may be connected to either the transmitter circuit **748** or receiver circuit **750** through a single switching operation of the switch **746**.

In an alternative embodiment, the sensor and processing system of FIG. **700** may be employed in the context of a smart phone, tablet, or other touch screen application as opposed to a traditional keyboard. In particular, the processing system may be configured to dynamically reconfigure the sensor to switch between a low sensitivity, high resolution near field mode for use with an active pen (which has a relatively strong signal), and a high sensitivity, low resolution far field mode for detecting a finger (which has a relatively weak "signal").

FIG. **8** is a schematic diagram of an inter-digitated capacitive sensor superimposed with a graphical representation of an increasing area of contact with a dielectric material for use in a finger detection mode. More particularly, an exemplary capacitive force sensor **800** includes a transmitter node **802** having a plurality of transmitter electrodes **803**(*a*), **803**(*b*), and a receiver node **804** having a plurality of receiver electrodes **805**(*a*), **805**(*b*). In a preferred embodiment, each transmitter and receiver electrode is in the range of 10-100 micrometers (um) thick, and preferably about 50 um, and adjacent electrodes may be separated by a gap **810** of approximately the same dimension.

With continued reference to FIG. **8**, a deformable dielectric material exhibits an initial area of overlap **812** with the underlying sensor when the key cap is not activated. The initial contact area **812** may be zero or non-zero. The deformable dielectric exhibits a first area of overlap **814** with the sensor during an early stage of a keystroke, and a second area of overlap **816** during a latter stage of the keystroke.

A keyboard input device is thus provided which includes a plurality of key assemblies configured to be pressed by an input object, wherein each of a subset of the key assemblies comprises a key cap and a capacitive sensor disposed underneath the key cap, and a processing system communicatively coupled to and configured to selectively operate each capacitive sensor in a first mode and a second mode, wherein the first mode operates each capacitive sensor in a fine pitch configuration and determines a first variable capacitance, and the second mode operates each capacitive sensor in a coarse pitch configuration and determines a second variable capacitance.

In an embodiment the first mode corresponds to near field detection and the second mode corresponds to far field detection.

In an embodiment, the processing system is further configured to determine at least one of a finger presence proximate the key cap and key cap motion from at least one of the first and second variable capacitances. Key cap motion may be determined based on the first variable capacitance, and finger presence may be determined based on the second variable capacitance.

In an embodiment, the processing system is configured to switch between the first and second modes at a frequency in the range of about 1 to about 50 Hz.

In an embodiment, each of the subset of key assemblies may include a planar translation effecting (PTE) mating feature including a ramp configured such that the key cap translates vertically and laterally in a planar manner relative to the PTE feature in response to the input object contact.

In an embodiment, the processing system may be configured to switch between the first and second modes using a varying duty cycle.

In an embodiment, the capacitive sensor comprises a plurality of parallel conductors separated by a distance in the range of about 50 to about 150 micrometers, wherein the fine pitch configuration comprises an inter-digitated pattern of alternating transmitter and receiver electrodes, and the coarse configuration comprises at least a first subset of adjacent transmitter electrodes and at least a second subset of adjacent receiver electrodes.

In an embodiment, the capacitive sensor includes at least three or four ohmically isolated electrodes, and the processing system includes transmitter circuitry and receiver circuitry and is configured to selectively connect the three electrodes, respectively, to the transmitter circuitry and receiver circuitry.

In an embodiment, the processing system may include an external switch and a microcontroller configured to selectively connect the electrodes to the transmitter circuitry and receiver circuitry using the external switch.

In an embodiment, the processing system is configured to operate in the second mode until a finger is detected, and to time multiplex between the first and second modes in response to detection of the finger.

In an embodiment, a compressible dielectric may be disposed between the key cap and the capacitive sensor, wherein the compressible dielectric and the capacitive sensor exhibit an area of contact which increases during a down stroke of the key cap, thereby changing at least the first variable capacitance when in the first mode.

In an embodiment, the area of contact may increase substantially monotonically with downward key cap motion.

A processing system is also provided for a keyboard input device of the type including a plurality of key assemblies each having a key cap and a capacitive sensor disposed underneath the key cap. The processing system is configured to be communicatively coupled to each of the capacitive sensors and configured to selectively operate each capacitive sensor in a first mode and a second mode; wherein the first mode operates the capacitive sensor in a fine pitch configuration and determines a first variable capacitance, and the second mode operates the capacitive sensor in a coarse pitch configuration and determines a second variable capacitance; and wherein key cap motion is determined based on the first variable capacitance and finger presence is determined based on the second variable capacitance.

In an embodiment, the processing system may be configured to operate in the second mode until a finger is detected, and to time multiplex between the first and second modes in response to the detection of a finger.

In an embodiment, the capacitive sensor may include a plurality of parallel conductors separated by a distance in the range of about 50 to about 150 micrometers, and the processing system may be configured to switch between the first and second modes at a frequency in the range of about 20 to 100 Hz, and preferably about 50 to 100 Hz.

In a keyboard of the type including a key cap and a capacitive sensor disposed underneath the key cap, a method is provided for: operating the capacitive sensor in a first mode configured for near field detection and generating a first variable capacitance; operating the capacitive sensor in a second mode configured for far field detection and generating a second variable capacitance; determining key motion based on the first variable capacitance; and determining finger presence based on the second variable capacitance.

In an embodiment, operating the capacitive sensor in the first mode may involve configuring the capacitive sensor in a fine pitch arrangement of parallel conductors; and operating the capacitive sensor in the second mode may involve configuring the parallel conductors in a coarse pitch arrangement including a first subset of adjacent transmitter electrodes and a second subset of adjacent receiver electrodes.

Thus, the techniques described herein can be used to implement any number of devices utilizing different touchsurface assemblies, including a variety of keyboards each comprising one or more key assemblies in accordance with the techniques described herein. Some components may be shared when multiple touchsurfaces are placed in the same device. For example, the base may be shared by two or more touchsurfaces. As another example, the keyswitch sensor may be shared through sharing sensor substrates, sensor electrodes, or the like.

The implementations described herein are meant as examples, and many variations are possible. As one example, any appropriate feature described with one implementation may be incorporated with another. As a first specific example, any of the implementations described herein may or may not utilize a finishing tactile, aesthetic, or protective layer. As a second specific example, ferrous material may be used to replace magnets in various magnetically coupled component arrangements.

In addition, the structure providing any function may comprise any number of appropriate components. For example, a same component may provide leveling, planar translation effecting, readying, and returning functions for a key press. As another example, different components may be provide these functions, such that a first component levels, a second component effects planar translation, a third component readies, and a fourth component returns. As yet another example, two or more components may provide a same function. For example, in some embodiments, magnets and springs together provide the return function, or the ready and return functions. Thus, the techniques described in the various implementations herein may be used in conjunction with each other, even where the function may seem redundant. For example, some embodiments use springs to back-up or augment magnetically-based ready/return mechanisms.

What is claimed is:

1. A keyboard input device comprising:

a plurality of key assemblies configured to be pressed by an input object, wherein each of the plurality of key assemblies comprises a keycap and a capacitive sensor, wherein each capacitive sensor disposed underneath each keycap for said each key assembly; and

a processing system communicatively coupled to the plurality of key assemblies and configured to:

selectively operate said each capacitive sensor of said each key assembly in a first mode for near field detection and a second mode for far field detection, wherein the first mode operates said each capacitive sensor of said each key assembly in a fine pitch configuration and determines a first variable capacitance, and the second mode operates said each capacitive sensor of said each key assembly in a coarse pitch configuration and determines a second variable capacitance,

determine, for said each key assembly of the plurality of key assemblies and from the first variable capacitance, a keycap motion of the keycap of said each key assembly, and

determine a finger presence proximate to the keycap of said each key assembly from the second variable capacitance,

wherein the fine pitch configuration, of said each capacitive sensor of said each key assembly, comprises an inter-digitated pattern of alternating parallel transmitter and receiver electrodes, and the coarse configuration, of said each capacitive sensor of said each key assembly, comprises at least a first subset of adjacent transmitter electrodes and at least a second subset of adjacent receiver electrodes.

2. The keyboard input device of claim **1**, wherein the processing system is configured to switch between the first and second modes at a frequency in the range of about 1 to about 50 Hz.

3. The keyboard input device of claim **1**, wherein said each of the plurality of key assemblies further comprises a planar translation effecting (PTE) mating feature including a ramp configured such that the keycap of said each key assembly translates vertically and laterally in a planar manner relative to the PTE feature in response to the input object contact.

4. The keyboard input device of claim **1**, wherein the processing system is configured to switch between the first and second modes using a varying duty cycle.

5. The keyboard input device of claim **1**, wherein said each capacitive sensor of said each key assembly comprises a plurality of parallel conductors separated by a distance in the range of about 50 to about 150 micrometers.

6. The keyboard input device of claim **1**, wherein:

said each capacitive sensor of said each key assembly comprises at least three ohmically isolated electrodes; and

the processing system comprises transmitter circuitry and receiver circuitry, and is further configured to selectively connect the three electrodes, respectively, to the transmitter circuitry and receiver circuitry.

7. The keyboard input device of claim **6**, wherein:

the processing system further comprises an external switch and a microcontroller configured to selectively connect the three electrodes, respectively, to the transmitter circuitry and receiver circuitry through the external switch.

8. The keyboard input device of claim **1**, wherein the processing system is configured to operate in the second mode until a finger is detected, and to time multiplex between the first and second modes in response to detection of the finger.

9. The keyboard input device of claim **1**, further comprising, for said each key assembly, a compressible dielectric disposed between the keycap and the capacitive sensor.

10. The keyboard input device of claim **9**, wherein the compressible dielectric and the capacitive sensor of said each key assembly exhibit an area of contact which increases during a down stroke of the keycap of said each key assembly, thereby changing at least the first variable capacitance when in the first mode.

11. The keyboard input device of claim **10**, wherein the area of contact increases substantially monotonically with downward the keycap motion.

12. A processing system for a keyboard input device comprising a plurality of key assemblies, each key assembly of the plurality of key assemblies comprising a keycap and a capacitive sensor, wherein each capacitive sensor disposed underneath each keycap for said each key assembly, wherein the processing system is configured to be communicatively coupled to the plurality of key assemblies, and configured to perform functionality comprising:

selectively operating said each capacitive sensor of said each key assembly in a first mode for near field detection and a second mode for far field detection, wherein the first mode operates said each capacitive sensor of said each key assembly in a fine pitch configuration and determines a first variable capacitance, and the second mode operates said each capacitive sensor of said each key assembly in a coarse pitch configuration and determines a second variable capacitance,

determining, for said each key assembly of the plurality of key assemblies and from the first variable capacitance, a keycap motion of the keycap of said each key assembly, and

determining a finger presence proximate to the keycap of said each key assembly from the second variable capacitance,

wherein the fine pitch configuration, of said each capacitive sensor of said each key assembly, comprises an inter-digitated pattern of alternating parallel transmitter and receiver electrodes, and the coarse configuration, of said each capacitive sensor of said each key assembly, comprises at least a first subset of adjacent transmitter electrodes and at least a second subset of adjacent receiver electrodes.

13. The processing system of claim **12**, further configured to operate in the second mode until a finger is detected, and to time multiplex between the first and second modes in response to the detection of a finger.

14. The processing system of claim **12**, wherein the capacitive sensor of said each key assembly, comprises a plurality of parallel conductors separated by a distance in the range of about 50 to about 150 micrometers, and further wherein the processing system is configured to switch between the first and second modes at a frequency in the range of about 50 to 100 Hz.

15. A method for operating a keyboard comprising a plurality of key assemblies, wherein each key assembly of the plurality of key assemblies comprising a keycap and a capacitive sensor, wherein each capacitive sensor disposed underneath each keycap for said each key assembly, the method comprising:

selectively operating said each capacitive sensor of said each key assembly in a first mode configured for near field detection and a second mode configured for far field detection, wherein the first mode operates said each capacitive sensor of said each key assembly in a fine pitch configuration and determines a first variable capacitance, and the second mode operates said each capacitive sensor of said each key assembly in a coarse pitch configuration and determines a second variable capacitance;

determining, for said each key assembly of the plurality of key assemblies, and from the first variable capacitance, a keycap motion of the keycap of said each key assembly; and

determining a finger presence proximate to the keycap of said each key assembly from the second variable capacitance,

wherein the fine pitch configuration, of said each capacitive sensor of said each key assembly, comprises an inter-digitated pattern of alternating parallel transmitter and receiver electrodes, and the coarse configuration, of said each capacitive sensor of said each key assembly, comprises at least a first subset of adjacent transmitter electrodes and at least a second subset of adjacent receiver electrodes.

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